Factors Influencing Occurrence, Scale, Mobility, Runout, and Morphology of Mass Movements on the Continental Slope

Homa Lee
U.S. Geological Survey
phone: (650) 329-5485 fax: (650) 650-5198 email: hjlee@usgs.gov

Award Number: N0001403IP20008
http://marine.usgs.gov/

LONG-TERM GOALS

Our long term goals are to understand how geotechnical and physical properties develop in marine sedimentary deposits on continental margins as a result of various biological, geochemical and mechanical processes. From these considerations we also want to understand how these properties influence sediment transport processes and the development of the final geomorphology. Our studies include predicting the stability of slopes within the continental terrace and distinguishing morphologic features caused by slope failure from those caused by other gravity-driven processes, including turbidity-current flow. A major component is the development of mobility so that we can understand the transition from initial slope failure to the development of debris flows and turbidity currents. Another component is predicting the rheological properties that determine the dynamics of such flows.

OBJECTIVES

Our main objectives for FY03 focused on the following: (1) complete our final contributions to STRATAFORM related to long coring and data analysis; (2) initiate our involvement in project PASTA and EuroSTRATAFORM by focusing our study on (i) the development of flows in marine sediment and (ii) evaluating the origin of crenulated sediment in the Adriatic Sea; (3) estimate the effect of bioturbation on strength development ; (4) quantify the impact of repeated earthquake events on sediment shear strength. Within EuroSTRATAFORM we are continuing to work on (5) predicting sediment mobility and the regional variation of erodability, stability, and penetrability of the nearshore seabed by (6) developing index property relationships that can be determined easily or, potentially, mapped remotely in order to identify regionally distributed geotechnical properties. Another objective of FY03 was to (7) assess the signatures of catastrophic events to determine whether they are produced by deformational (landsliding) or depositional (turbidity current sediment waves) processes (Lee et al., 2002). A final objective was to (8) provide modelers with easily determined relationships that can be used to predict sediment strength and rheological properties of sediments.

APPROACH

Our research focuses on the sedimentological and environmental factors determining sediment properties and their influence on failure and post failure behavior. We develop improved correlations between engineering classifications and strength factors. We relate compressibility, physico-chemical properties and strength to sediment microstructure and sediment stress history. We simulate sediment accumulation in specially designed large cells. We measure sediment rheological properties in a viscometer. Geotechnical properties are related to sediment density state, obtained from detailed logs of downcore variability of sediment density and sound velocity. Basic strength parameters are obtained

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE **Factors Influencing Occurrence, Scale, Mobility,Runout, and Morphology of Mass Movements on the Continental Slope**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Geological Survey,, , , Menlo Park,,CA, 94025**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Our long term goals are to understand how geotechnical and physical properties develop in marine sedimentary deposits on continental margins as a result of various biological, geochemical and mechanical processes. From these considerations we also want to understand how these properties influence sediment transport processes and the development of the final geomorphology. Our studies include predicting the stability of slopes within the continental terrace and distinguishing morphologic features caused by slope failure from those caused by other gravity-driven processes, including turbidity-current flow. A major component is the development of mobility so that we can understand the transition from initial slope failure to the development of debris flows and turbidity currents. Another component is predicting the rheological properties that determine the dynamics of such flows.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

using triaxial drained and undrained tests and undrained cyclic tests. Using available bathymetry, and seismic profiles, we develop models for stability, mobility, and risk (Leroueil et al. 2003). Driving stresses are balanced against strength variations in a geographic Information System (GIS) to obtain a regional estimate of relative slope stability. Seismic loading is simulated in the laboratory using cyclic shear testing of representative marine sediment. Seismic strengthening is evaluated within the context of critical state soil mechanics.

Our work is fully coordinated with a matched project at Laval University directed by Jacques Locat. Key individuals, at Laval: Jacques Locat, Jean-Marie Konrad, Serge Leroueil, Marie-Claude Lévesque and Pierre Therrien: strength and compressibility measurements, SEM studies, rheology measurements, and simulation of sediment accumulation; at the USGS: Homa Lee, Dianne Minasian, Pete Dartnell, and Kevin Orzech: physical property logs of sediment cores and relations between geotechnical and classification properties, algorithms relating sediment properties, environmental factors, and slope stability within the framework of a GIS, and strength development from seismic shaking.

WORK COMPLETED

During FY 03, we completed work related to the STRATAFORM project on the New Jersey margin and made significant advances in completing related publications. We contributed to the effort in evaluating the potential use of the GLAD800 for coring on the shelf and slope and providing geotechnical quality samples. We completed SEM and mineralogical analyses of San Francisco Bay mud samples used to test our hypothesis of seismic strengthening (Lévesque and Locat 2003). We conducted simulations of repeated seismic loading and developed estimates of the magnitude of shear strength that could be gained in such a manner (Figure 1). We conducted a survey of rapid flows in marine sediment and presented a keynote paper on this subject at an international meeting (Lee and Locat, in press).

RESULTS

Our analysis of the GLAD800 indicated that this drilling platform is not ready yet (as of November 2002) for operating efficiently on the shelf under typical wave conditions. Our final slope stability analysis of the Hudson Apron along the New Jersey Margin has indicated that if the ODP geotechnical investigation is correct, the actual factor of safety of the slope is marginal and that the required pore pressures to trigger a failure had to be significantly high. For the Hudson Apron site, the yield strength required to maintain the slope in a stable state is close to the measured undrained shear strength at a depth of about 150 to 200 m below the sea floor. Our preliminary analysis of the microstructure of Ortona samples in the Adriatic Sea identified a flow layer, as presented at the EuroSTRATAFORM session at the AGU meeting in Nice (Lévesque et al. 2003). We are in the process of defining ways to quantify the bio-porosity index of a sediment, so that we can illustrate the extent of bioturbation by looking at down core variations in the index. We showed that significant strength increases (greater than 50%) can be achieved by repeated non-failure seismic loading events.

IMPACT/APPLICATION

Relationships developed in this project show the importance of sediment liquidity index and seabed density profiles in representing the physical behavior of marine sediment. These values can be used to predict regional slope stability, rheological behavior of debris flows, and resistance to object penetration. General strength-density relationships can be used for modeling sediment accumulation

and stability. We are also currently working on the definition of a bio-porosity index to include in the measurement of the shear strength of near surface sediments. By understanding the influence of seismic strengthening, we can better explain the relative lack of slope failures in seismically active environments. Models of strength development for these environments can be used to forecast object penetration and other engineering issues.

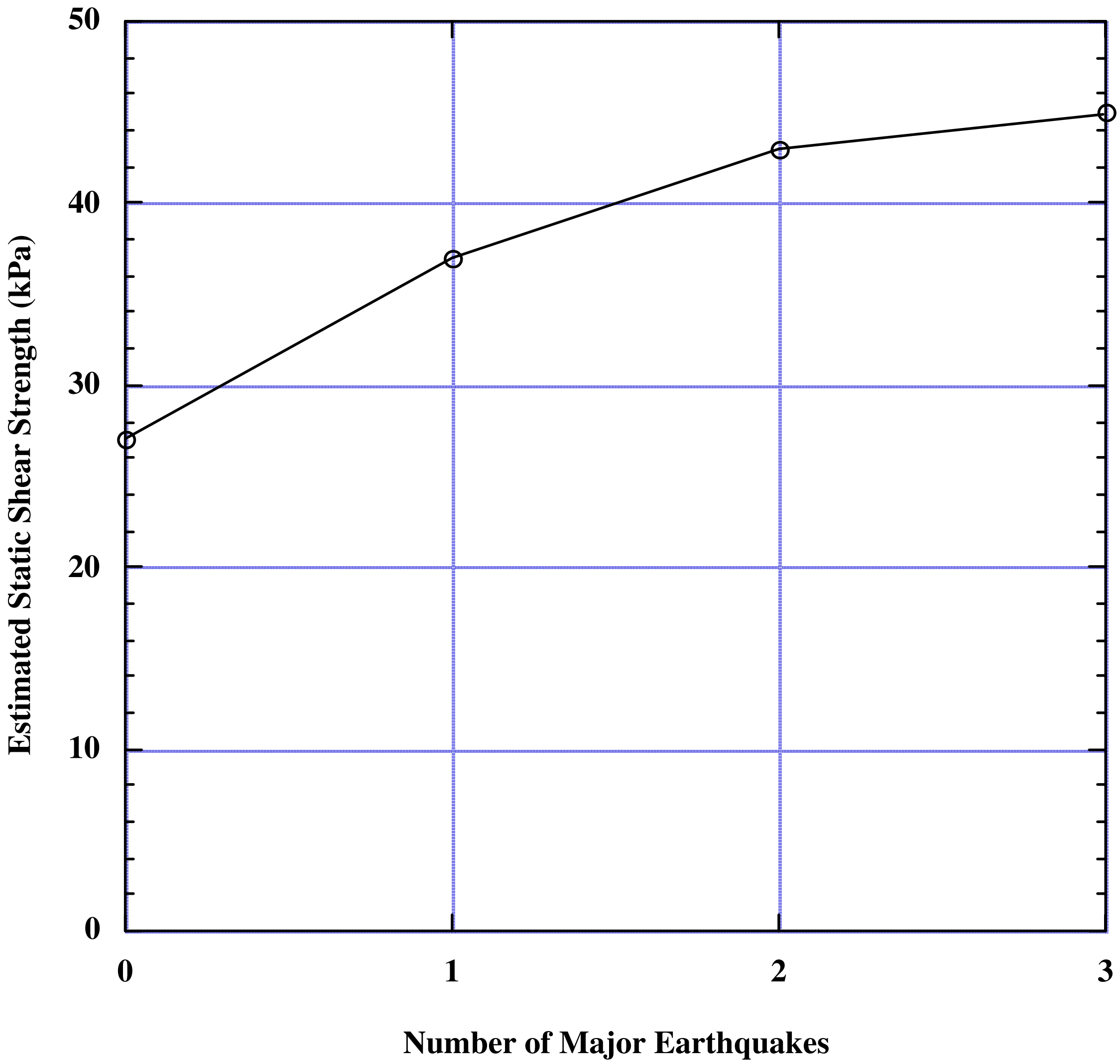

Figure 1. Results of cyclic simple shear tests on characteristic marine sediment. These results show that the application of repeated simulated earthquake loading events, which are not sufficient to fail the sediment themselves, actually cause the sediment to be stronger (in this case by 67% after 3 earthquakes) and better able to resist earthquake loads in the future.

TRANSITIONS

Geoacoustic properties are being used by mappers and acousticians to identify lithologies acoustically (Locat and Sanfacon, 2002). Rheological properties (Locat, 1997) are being used by modelers to represent debris flows (Imran et al. 2001). Landslide generation models are being used by landscape evolution modelers. Offshore research groups interested in margin and in oil and energy development

were used as a platform to present our knowledge on submarine slope stability and hazard acquired as part of STRATAFORM. We have also contributed to a major effort in assembling all the existing knowledge on submarine mass movements and their consequences by publishing a book containing refereed papers on the topic (Locat and Mienert 2003) including papers by Lee et al. (2003) and Locat et al. (2003a) related to STRATAFORM. We also transfered our knowledge developed as part of STRATAFORM to those interested in tsunami modeling (Locat et al. 2003b).

RELATED PROJECTS

Lee has developed a USGS project to investigate sediment and pollutant transport on the Los Angeles margin that uses techniques produced by STRATAFORM. The development of this project benefited from approaches developed within STRATAFORM. Recently, a group of Canadians led by J. Locat, and H. Lee developed a new project with project COSTA (COntinental Slope STAbility) in Europe that will last until 2005.

REFERENCES

Imran, J., Parker, G., Locat, J., and Lee, H., 2001. A 1-D numerical model on muddy subaqueous and subareial debris flows. Submitted to ASCE Journal of Hydraulic Engineering. 127: 959-968.

Lévesque, M.-C., Locat, J., Trincardi, F., and Lee, H., 2003. Nature and microstructure of some late-Holocene Adriatic shelf sediments. EGU-AGU meeting in Nice, France. Abstract. [published]

Locat, J., 1997. Normalized rheological behavior of fine muds and their flow properties in a pseudoplastic regime. *In: Debris flow hazards mitigation, mechanics, prediction and assessment*. Water Resources Engineering Division, ASCE, pp. 260-269.

Locat, J., and Mienert, J., 2003. Submarine Mass Movements and Their Consequences. Kluwer Series on Advances in Natural and Technological Hazards No. 19, 540p. [published, refereed]

Locat, J., and Sansfaçon, R., 2002. Multibeam survey: a major tool for geosciences. Sea Technology, 43: 39-47.

Locat, J., Desgagnés, P., Leroueil, S., and Lee, H.J., 2003a. Stability of the Hudson Apron slope off New Jersey. In: Submarine mass Movements and Their Consequences, J. Locat and J. Mienert, Eds., Kluwer series on Natural and Technological Hazards, vol. 19, pp.: 257-270. [published, refereed]

Locat, J., Lee. H.J., and Locat, P., 2003b. Numerical analysis of the mobility of the Palos Verdes debris avalanche. Accepted for publication in Marine Geology. [in press, refereed]

Locat, J., Lee, H., and Locat, P., 2002. Analysis of Submarine Mass Movements and its Implication for the Generation of Tsunamis, with a Particular Reference to the Palos Verdes Slide, California. Submitted to Marine Geology.

Locat, J., and Lee, H.J., 2002. Submarine landslides: advances and challenges. Keynote presentation, 8th International Symposium on Landslides, Cardiff, U.K., June 2000. Canadian Geotechnical Journal, 39: 193-212.

PUBLICATIONS

Lee, H.J., Kayen, R.E., Gardner, J.V., and Locat, J., 2003. Characteristics of several tsunamogenic submarine landslides. In: Submarine mass Movements and Their Consequences, J. Locat and J. Mienert, Eds., Kluwer series on Natural and Technological Hazards, vol. 19, pp.: 345-354. [published, refereed]

Lee, H.J. and Locat, J., Mobilization of submarine flows: examples and questions, Proceedings, International Workshop on "Occurrence and mechanisms of flows in natural slopes and earthfills," Naples, 15 pp.[in press]

Lee, H.J., Syvitski, J.P.M., Parker, G., Orange, D., Locat, J., Hutton, E.W.H., and Imran, J., 2002 Distinguishing sediment waves from slope failure deposits:field examples, including the 'Humboldt Slide,' and modelling results, Marine Geology [in press, refereed]

Lévesque, M.-C., and Locat, J., 2003. Report analysis on San Francisco Bay Clay (Sample SBWR-43). Gregi Report no ULSFBS02-12, décembre 2002, 39p.

Leroueil, S., Locat, J., Lévesque, C., and Lee, H.J., 2003. Towards an approach for the assessment of the associated risk with submarine mass movements. In: Submarine mass Movements and Their Consequences, J. Locat and J. Mienert, Eds., Kluwer series on Natural and Technological Hazards, vol. 19, pp.: 59-68. [published, refereed]